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A Critical Investigation of Methods Applied to Multi-Configuration Households on Energy Consumption Patterns within the Building Performance Gap in the UK

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Abstract

This paper is a part of a project geared towards the analysis of multi-configuration household behaviour and determining the presence or absence of causal and statistical relationships within a code level 5 Eco-homes in Lincolnshire, UK. The research methodology follows a mixed method bottom-up approach to detail and extrapolate energy consumption within households. That is achieved using room-by-room occupancy and, activity logs, questionnaires that use both quantitative scales and extraction of qualitative information, data loggers and the use of an experimental footfall study.

The research utilizes the aforementioned methods through the digitization of data into manageable cross-compatible units, the extrapolation of energy and occupancy trends from self-observation tools. The study uses Excel to initially catalogue the raw data provided and created the functional relationships used to automate and manipulate the data sets to generate the energy/occupancy-time relationships to cover time-steps and different periods of use. In addition, the research is using a well-established high resolution behaviour modelling tool created by CREST, Loughborough as a validation benchmark for the extrapolated data as well as a tool to visually and contextually determine the gap in knowledge being addressed in the study. This phase of the research concludes by determining the validity of the data extrapolation methodology and its use as a low-cost framework to bypass the difficulty of studying houses not fitted with often-expensive smart metering systems.

Introduction

This paper is part of the researcher's process of reviewing the validity and efficiency of the data collection methods used during the pilot and data gathering phase of his study investigating user behaviour within the building performance gap. An introduction to the research background and its place within the performance gap will be outlined followed by a general overview of the methodology used within the study. Each tool used will be further detailed in its own section outlining its merits, constraints and previous work done with similar ideas where applicable.

Problem Background

Building regulation agencies in the UK have rolled out regulations to impact a deterministic effect on citizens' energy consumption by regulating how houses are constructed, how users are expected to use the buildings and the projected savings (Odeyale etal, 2013; Warren, 2014). Eco-homes introduction and the development of its subsequent Code for Sustainable Homes (CfSH) in 2007 have impacted the UK housing market as the regulations were enforced through Part L. Whist incentives and economic reasons supported the design of higher CfSH standard buildings or other standards such as PassivHaus.

Building Standards & User Behaviour

The last three years however following the phasing out CfSH announcement and the Building Regulations Review by Parliament, level four standards equivalent were enforced as base Building Regulations, whilst the development of Home Quality Mark (HQM) (HQM and BRE, 2015) standard is underway that still used Standard Assessment Procedure (SAP) as a standard for calculation of user energy requirement. Prior to the transitional shift, the PROBE studies by CIBSE (1995-2002) identified the importance of accounting for dynamic user behaviour and lack of proper accounting for it, was a cause of discrepancies. This produced a set of documents and a dataset of 20,000 user behaviour results known as the Time Use Study (TUS) and allowed the funding of the Building Performance Evaluation project (Tse and Colmer, 2014). During the transitional shift leading to this, collaborative research led by funding from Innovate UK, Zero Carbon Hub, university and industry partners identified and detailed the causes leading to the phenomenon of the Performance Gap (Zero Carbon Hub, 2015), one that the HQM (HQM and BRE, 2015) and other international efforts are aiming to bridge. By proving the existence of the gap, it became imperative to adapt and optimize methods to investigate those phenomena towards bridging it Such efforts include international collaborations such as Annex 66 (2013), whilst standards produced in parallel internationally such as the Australian National Australian Built Environment Rating System (NABERS) and the Nationwide House Energy Rating Scheme (NatHERS) which are directed towards studying user behavioural and operational building performance rather than focusing on design or target-only design.

Within the context of BREEAM building codes (CfSH and the upcoming HQM), energy calculations are accounted to achieving a reduction in emissions based on the calculations done within the SAP's

technical document/ application. Said calculations, mainly within SAP's occupancy calculation (Henderson and BRE, 2008) and tables 9 within the SAP document (ref) regarding space heating which disregard personal comfort and variations in ambient space temperature (BRE and DECC, 2014), whilst serving as a benchmark in the design process, upon post-occupancy evaluation, the benefit of a probabilistic model would be needed for comparison to validate the real life trend against calculations and thus be able to decide whether the performance gap was due to short-sightedness within SAP or if users' behaviour was too unpredictable for a fixed or dynamic model to estimate (Richardson et al., 2010; Gruber and Prodanovic, 2012; Blight, 2015)

Occupant Behaviour

Through investigation of the literature, the researcher has observed and attributed occupants' behaviour to a number of documented theories. Including the theory of planned behaviour (Ajzen, 2011) such as: environmental physical probabilism (Kaiser and et al, 1996; Hope et al., 2017), both of which were observed through the methods to be discussed in the following sections. Starting at a macro scale with the choice of living in an eco-house by following an assumed theory of self-selection (Michelson, 1977). How user behaviour within their dwelling can be recognized through the models of planned behaviour; addressing the premise that behavioural beliefs, normative beliefs and perceived control over their personal comfort by being able to alter their habitat (Borden and Schettino, 1979; Ajzen, 2011; Blight, 2015). Finally, complimented by probabilism (Kaiser and et al, 1996), a midway point between environmental deterministic and probabilistic factors. The assumption that users are likely to perform actions due to a deterministic environmental factor, however their personal comfort, external criteria and free choice determines if they are likely to do it (Borden and Schettino, 1979).

Examples of these factors that have been previously established are internal and external climate; predictive mean vote of personal comfort; architectural layout and spatial functions; occupancy patterns; age factors; employment and associated routine. The range of factors that operate within these theories are impractical to empirically quantify as they change depending on the conditions surrounding the subjects as well as flow with their own perception and experience of space (Parys, Saelens and Hens, 2011; ElNokaly & ElSeragy, 2012). Thus, the researcher operated on the concept that behaviour of residents of eco-houses who share values of having chosen to research and buy these houses as well as operate under overall deterministic operational design.

Whilst factors such as their age, employment and, occupancy patterns would vary due to probabilistic factors that could not be isolated but perhaps regressed into consumption trends that would serve as a comparative baseline for design or post-occupancy evaluation by generating profiles based on that variation to extrapolate Multi-Household Configuration Pattens (MHCPs). However, a limitation to this research is to account for the variable occupant numbers per dwelling, their employment and their age would create a variation in results that cannot be considered statistically significant on a large scale without acquiring a wider sample and testing them in further research that is not constrained by time (Barlett et al., 2001). Thus, analysing it on a case-by-case basis, and allowing for the creation of a methodology and toolkit to be used would allow for expanded research and exploration of further scenarios (Pustejovsky, 2015)

Methodology Summary

The research is conducted using a mixed method methodology (HO et al., 2006, Cohen et al., 2011) that is designed to extract as much behavioural and usage information as possible from residents and their lifestyle with minimum intrusiveness. To that aim, the researcher identified five methods to use in the study which are used to investigate the different elements of user behaviour identified.

- Daily room-by-room occupancy logbooks at a 30-minute interval,
- Daily Activity logbooks at a 30-minute interval,
- Footfall Plan of movement representing a typical day,
- Temperature & Relative Humidity Dataloggers,
- Semi-Structured Questionnaires.

The results of each house investigated will be critically analysed in depth, within its own merit then run through an investigative cross-case analysis (VanWynsberghe & Khan, 2008) to deduce influential demographic factors (Anderson et al., 2017) within the case study as well as regression of the empirical data gathered. Those factors are compared against the SAP (SAP Printout, 2015) methodology results the buildings are originally designed with and used to prove the gap within the case study. In addition, each individual house is critically analysed using the behavioural performance reports and measurements logged on the Building Data Exchange (Digital Catapult, 2016). Each case study also produces a set of qualitative data through semi-structured questionnaires performed in a face-to-face interview setting and recollective memory interrogation (Geer, 1991, Witzel, 2000, Turner, 2010; ElNokaly & Keeling, 2016). That data is then translated into compatible quantitative values to be used within the regression modelling component of the research (Dixon-Woods et al., 2005).

Structured Interviews + Questionnaire

The researcher's first tool was to conduct a set of semi-structured interviews at the start of the study, its task was to gather demographic data about each of the houses during the recruitment phase. This was followed by quality of life discussions to collect transcendental phenomenological information (Moustakas, 2010) of occupants' perception of their life and actions. This is done using investigative recollection (Fisher et al., 1989) of this general behaviour as perceived by the collective household.

The figure below details the points during the main research phase through-out which interviews in one form or another were conducted.

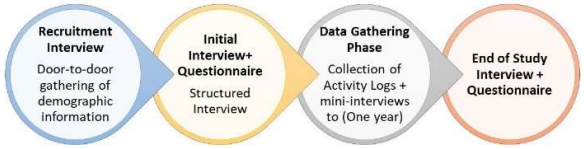


Figure 1 Prevalence of face-to-face questioning during different project phases

Recruitment Interviews

Due to the time constraint of cold-call recruitment, these short interviews had to be structured into a set of concise brief questions to gauge their suitability and interest in the project and willingness to participate. Upon narrating a brief introduction of the research team and the project (Mowatt, 2015; Rebuffet-Broadus, 2015), the following questions were asked.

Table 1 Sample of first communication log with residents

Are you interested to learn more about the project? (Yes/No)
Are you interested in participating in the project? (Yes/No)
What age groups currently live in this residence? *0-4 / 4-17 / 18-45 / 46-60 / 61+*
What employment groups do the residents fall in?
Would you be interested in participating in the datalogger part of the research? (Yes/No)
Contact information: Email/Phone
How long have you lived in this house?
Have you chosen it because it is an Eco-House? (Yes/No)
Potential meeting date: …/…/……

Residents were generally trusting upon seeing identification and proof of the research being conducted within an ethical framework. Having collected information themselves about the research team, university, aims and what the research entails, they were inclined to share the information. Whilst not detailed in this paper, the case study formed a promising candidate for theory of self-selection. Being house owners of properties that start at £225,000 – £350,000 in 2015, these properties being downsized alternatives, second homes or upgrades. And assumed annual household income from managing businesses, full-time, part-time technical and administrative professions. In addition, it was observed the ownership of multiple cars per household, brand name electronics and habitual behaviour such as travel. The research came to conclude by drawing liberal assumptions that the residents of this housing project fell between an Established Middle Class and Elite Class (BBC, 2011; Savage et al., 2013) thus eliminating the restriction of finances as a factor of selection. Secondly, whilst racial and ethnic differences were mildly observed, their impact was detected in their cognitive environmental behaviour rather than reasons for purchasing these houses. The latter is a factor the researcher would allow to exist as the research is based on investigating the demographic factors contributing to energy consumption and whilst not imperative it provides insight to the varying comfort levels of the residents within the boundaries of adaptive thermal comfort and difference in UK climate to home climate (Mishra and Ramgopal, 2013). However, whilst this is observed within interviews, at this stage it cannot be identified as a source of variable consumption (Hong et al., 2009).

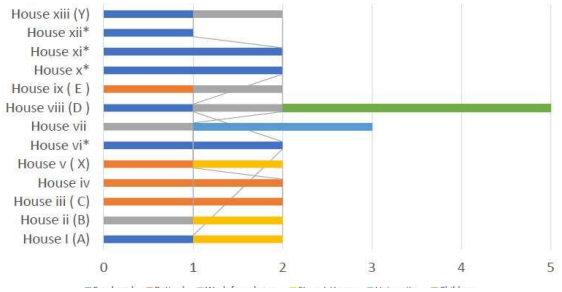


Figure 2 Summary of the various employments in households

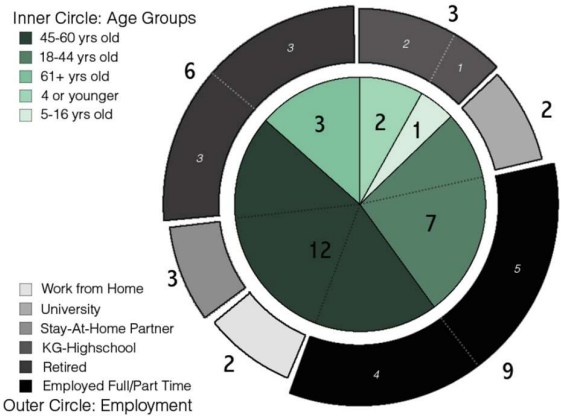


Figure 3 Detailed breakdown of age-employment relationships

Whilst cold-calling is generally considered a nuisance (Tyrer, 2003), in this instance was essential to the project, the housing compound approached was privately owned, did not have a collective Home Owners Association and there was no viable alternative to communicate with the residents prior to visiting. In addition, the developing company was not inclined to assist due to their concern that any errors would be detected within their design and construction and buyer information is considered confidential. One of the factors listed by ZCH (2015) that leads towards a performance gap.

The attempt was successful for a blunt-force method like this, bringing in a 69% response rate to the recruitment process as well as providing information about the other houses that did not respond due to: Overall lack of interest in a cold caller, Lack of interest in the project, Unavailable due to work schedule, Special needs/Elderly person unable to respond.

The results from this phase showed that the housing project had the employment diversity needed to continue the research, a mixture of various households with different residents, compositions and age groups. Further aggregating this information, the researcher could visualize the age-employment relationships within the

housing project in general to determine its validity as a case study (Yao & Steemers, 2005).

Initial & End-of-Study Semi-Structured Questionnaires

As a tool, semi-structured questionnaires allow for the marriage of two important and expressive data gathering methodologies; set quantitative responses and the ability to introduce a qualitative response. And in this particular study, they were conducted in face-to-face appointments that are akin to interviews in their detailing as well as having been recorded using a phone recorder application. Each question is composed of two sections, the quantitative portion, to which a question can be answered by choosing an appropriate number that reflects their level of comfort or satisfaction on a Likert scale from one to five. In addition to a follow up question that asks them to detail the perceptive reasoning behind choosing that response according to their experience living in the dwelling. The importance of the values recorded is to create a scoring system per house to be used for a regression analysis between their predicted energy consumption, their demographic status and the overall housing satisfaction score. The table below details the different criteria and scores awarded by the occupants of the housing investigated, the table is a percentage of scores awarded per criteria by all questionnaire participants.

Table 2 Quantitative findings of the perception and satisfaction questionnaire over the set of seven studied houses.

	Likert Scale of Occupants Perception (%)				
Performance Criteria	**1- Lowest**	**2**	**3- Indifferent /Moderate**	**4**	**5-High**
Understanding MHRV systems	0.00	0.00	14.29	***Aware*** 42.86	42.86
MHRV Integration	0.00	0.00	14.29	***Aware*** 71.43	14.29
Airtightness and MHRV	0.00	14.29	0.00	***Aware*** 57.14	28.57
Consistency of temperature	14.29	28.57	28.57	14.29	14.29
Comfort-Summer	0.00	***Hot*** 42.86	0.00	28.57	28.57
Comfort-Winter	0.00	28.57	0.00	***Comfortable*** 42.86	14.29
Temp. Variance-Summer	0.00	14.29	28.57	14.29	***High Fluctuation*** 42.86
Temp Variance-Winter	0.00	28.57	0.00	28.57	28.57
Space temp - Summer	0.00	14.29	0.00	28.57	***High*** 42.86
Space Temp-Winter	0.00	28.57	0.00	28.57	28.57
Humidity Summer	0.00	0.00	***Acceptable*** 42.86	28.57	28.57
Humidity-Winter	0.00	0.00	***Acceptable*** 57.14	14.29	14.29
Air Freshness-Summer	28.57	0.00	14.29	0.00	***Fresh Air*** 57.14
Air Freshness-Winter	28.57	14.29	14.29	0.00	28.57
Odour- Summer	0.00	28.57	14.29	14.29	***No Odour*** 42.86
Odour- Winter	0.00	28.57	14.29	14.29	28.57
Air change rate	0.00	0.00	***Moderate*** 57.14	28.57	14.29
Natural Exposure	0.00	14.29	0.00	28.57	**Well Lit** 57.14
Artificial Lighting	0.00	0.00	28.57	***Good*** 42.86	28.57
Ventilation Control	0.00	***Very Poor*** 42.86	0.00	28.57	28.57
Space Cooling Control	0.00	***Very Poor*** 42.86	14.29	28.57	14.29
Space Heating Control	14.29	0.00	14.29	***Very Good*** 42.86	28.57
Lighting System Control	0.00	14.29	0.00	42.86	42.86

The detailed information above shows a percentage of average values between 40-60% over criteria of comfort, perception of thermal stability and thermal intensity. In this case, average percentages are an indication of the norm of residents occupying the case study. However, since this assessment only involves houses that have been studied without involving data mined from the TUS or Building Data Exchange databases thus the values are only representative of houses compared to identical build design, quality and hardware, constructed by the same company.

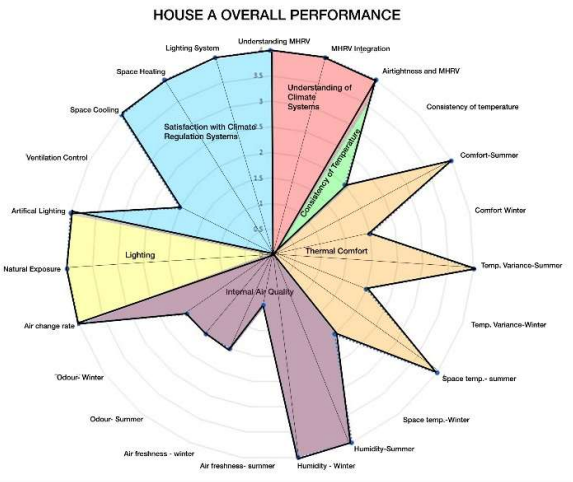


Figure 4 Rose-map of allotted points, colour coded to six categories of questions

The scores obtained from the questionnaire were translated to multiple scores out of a total of 30 (five-point average for each of the six sections), or an overall score of 115 (five-point Likert scale per each of the 23questions). The above figure gives an example of the final output of one of the studied houses. That score is ratified

Table 3 Quote extract from initiation questionnaire (Aly et al, 2017)

How well do you understand the integration of MHRV in the passive strategies & active heating solutions of the house?
"Not well, however my husband maintains all the systems" "We attended a course on operation of eco-houses in Grimsby so we could know the basics of the heating and heat recovery system. We are still not entirely sure how it works but we're learning" "We have only lived here for the duration of one summer so we are not entirely sure how the building performs yet. It was quite warm so we did not need to operate any of the systems"
Time of day when you start turning on the lights?
All houses mentioned that they found that their lighting behaviour depends on real daylight hours, that information was validated by reviewing activity and occupancy logs.
How long have you lived in this house? Is this your first high performance/ecohouse?
"We used to live in a Victorian style house with 5 bedrooms that used to get quite cold and would run up quite a bill for heating. We decided to invest in a house like this hoping to cut down on bills especially now that we live alone after our children moved out" "I used to own another property that was marketed as ecohouse, I moved here to be closer to the city and closer to work"

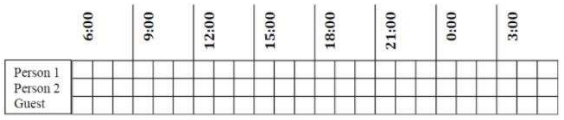
When asked about their heating practices, households responded differently. Instead each house tailored their experience based on their own thermal comfort and technical knowledge. The aforementioned responses show a partial rejection to theories of planned behaviour that building standards assume during design. The expectation that occupants would use technology and spaces in an expected manner according to a manual and behavioural design was not followed for various reasons, including but not limited to: houses not reaching maximum design occupancy; lack of control of individual spaces, pessimism towards feed-in tariffs and how they're calculated vs. how much is produced and used.

The emergence of cognitive behavioural responses -i.e. direct reactions due to an environmental stimulus- showed in various examples, such as House E that is occupied by a mechanical and energy engineer who has fine-tuned his house to his experience. And House B that is occupied by a couple, the husband Scandinavian in origin whilst the wife was British, which caused a divide in heating and occupied zones. The wife which had a lower tolerance for heat would occupy the lower floor at a lower set temperature of 21 C average whilst the husband would spend most of his time upstairs at a temperature of 24C. Depending on vertical convection currents, that the top floor is warmer and with warm air from the ground floor rising up to further heat up the space. That was observed in another house where presumably age, or age-related factors (loss of thermoregulation, frailty or medical conditions) was the factor (Waalen and Buxbaum, 2011).

Finally, for the end-of-term report, the researcher developed additional questions to be included to investigate how the project affected the subjects as well as provide a summary exercise for each of the participants as well as gathering similar quality log information from future short-term subjects. Those questions were designed after establishing a confident rapport with the subjects in order to extract more detailed information and be able to further aggregate the age and employment sets as well by the addition of the following questions:

1. How often do you try to conserve energy? (1-never to 5-always)
2. A table detailing the number of each employment variant in the household.
3. Importance of the following factors in saving energy: 1) Saving money, 2) Preservation of the environment, 3) Crowd mentality, saving energy because the community is doing the same.
4. Which months the automated heating system is turned on, each box indicates 2 weeks.

5. A simplified occupancy log of a typical working day and a typical weekend day



6. Have the residents gained new knowledge by participating in this project? Has it affected them positively or negatively?
7. Any perceived effects from observing their own activity and occupancy logs.
8. Any perceived effects from observing their footfall diagrams.
9. Any gained or discarded habits that contribute or negatively impact their savings.

In summary the questionnaire phases of this project have been designed to provide the researcher with sufficient detailed information to build a profile of consumption based on each household's energy attitude and occupancy through self-observation. However, whilst a powerful tool, questionnaires and self-reflection only offer insight to memory of recollection and perception, which have to be reinforced with empirical data from the Likert scales and the logbooks for the sake of this research project. Qualitative data is a supportive backbone for the quantitative information as a tool of insight to the workings of user behaviour that whilst unquantifiable can be accounted for by future researchers.

Activity and Occupancy Logbooks

Also known as "probe' studies, and guided by the CIBSE Probe (1995,1997, 2001) that developed the Building Use Study (BUS) Survey (CIBSE 1995; Arup, 2010; Kansara et at al, 2012; as well as Royal College of Arts (Dan et al, 2013), Cultural Probes (Gaver et al), the building performance evaluation papers including work by Gupta et al (2010; 2012; 2013; 2014) into investigating methods of receiving occupant feedback towards retrofitting and closing the feedback loop from industry to design (RIBA, 2013).

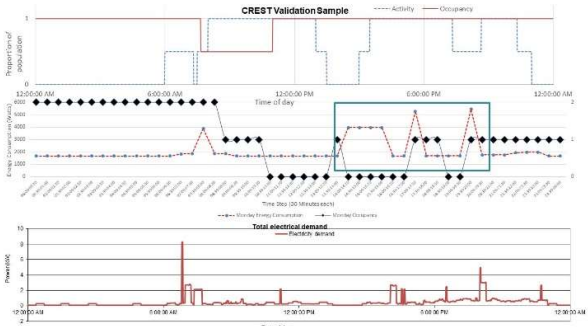


Figure 5 Comparison between the rough primary results, the occupancy and consumption results from the CREST tool

The logbooks have been designed as low-tech, low-cost alternative to other more intrusive equipment that can be purchased. The researcher had approached the research subjects to inquire about various methods of delivering the research package, including written/printed material to be filled by hand, digital files through Excel files and Google Spreadsheets or through a mobile application. The initial appeal towards a mobile application was thwarted by worried of intrusive or breech of personal information. In addition, the age groups, activity and tendencies of residents was towards a more manual approach by filling up their logbooks by hand. A beneficial approach for the research's sake as it provided guaranteed monthly opportunities to debrief and gain further elaboration on the forms and activity within. The time constraints and man hours involved, however constrained the number of logs to two per month that would be distributed due to the busy lifestyles of the occupants as well as to prevent loss of interest. The users are required to fill two weeks per month of typical behaviour (or atypical behaviour in case of national holidays and visitors) totalling an average set of twenty-four (24) collections per log category per house per year. Upon reviewing the literature and similar research done before, the researcher observed that subjects are not likely to change their activity within one given hour, thus a high-resolution profile of activities was neither feasible nor productive in this case. The researcher chose a resolution of 30-minute time-steps, with activities that occupy less than a time-step assessed on a case-by-case basis to identify their impact within the larger picture within the time frame of a single day and the accumulation within a year. By using the following equation, the excel sheet automatically calculates the maximum occupancy in dwelling at a certain time-step, this is required to avoid conflicts that arise due to doing multiple activities within the same interval using $If\ \sum Occ_{a-e} > Max_n\ Then\ Occupancy = Max_n, \sum Occ < Max_n\ Then\ Occupancy = \sum Occ$ where $\sum Occ_{a-e}$ is the total occupancy count of rooms a-e is. Max_n is the maximum number of occupants known to be available in the house at the time. The extracts below show the raw format of the extracted data, where the occupants would mark their occupancy/activity over the corresponding hours, often with extra detail that can be clarified during follow-up visits.

As observed above, even in the short period in the extracts above, there is a visually obvious repetition of certain activities and behaviours. Some of which might align with theories of planned behaviour that inform nation-wide policies such as reduced tariffs, and others habitual according to the lifestyle and demographic categories they fall into. By studying and analysing behaviour of typical weeks in this case study, probability-based relationships can be extrapolated. By studying this quantitative data in a critical analysis framework alongside the transcendental phenomenological narratives given during interviews of occupants' perceived behaviour, the researched can assign an environmental probability set of variables that accompany each empirical data set to criticise or justify the results of each individual house's investigation.

The researcher initially used static consumption values to deduce a worst-case scenario of the equipment previously surveyed in the house. By using these rough values however, it does not portray a realistic snapshot of used consumption. However, the values were used for validation prior to increasing the resolution to deduce the compatibility of measured data verses predictive data deduced from the TUS study to reinforce the CREST stochastic model. Appliance cycle information is based on the findings of programs such as the Market Transformation Program (DEFRA,2009), UK Department of Energy and Climate Change (DECC) Factsheets and assumed by Richardson et al (2010) in the proceedings accompanying the CREST predictive model.

Table 4 Comparison between DEFRA and surveyed appliance consumption

Appliance	*Cycles per day (#)*	*Cycle length (mins)*	*Cycle power (W)*	*Surveyed Appliances (W)*
Fridge/Freezer	16.67	20	155	46.67
Computer	1.23	300	141	85
Hi-FI (Sonos)	0.30	60	100	4.4
Flat LED TV	4.17	73	124	170
Hob	1.15	16	2400	3600
Kettle	4.16	3	2000	247
Dishwasher	0.66	60	1131	2300

Applied lighting models have been included using the CREST model, however users have reported specific lighting patterns that have to be validated opposite the predictions offered by the Richardson (2016) model for the prime reason of these houses being designed to utilise maximum solar exposure, thus affecting use of space, a closer look at the use and movement within spaces will be presented in the Footfall map section.

Footfall Tracing Maps

Part of an experimental investigation, the research team was interested in studying the relationship between the various activities, building form and the footfall around the building (Ahn et al., 2017). Processing this step is yet to be conducted however included in this paper is a sample of a footfall map showing the exact movements marked by the subjects occupying the sample household. They had marked their individual movements using different coloured ink for detailing, the researcher's role was to trace their movements in accordance with the room occupancy/activity log for validation. The results of this section would undergo a cross-case analysis against results done by other circulation predictive models, including IES-VE's Simulex and SmartMOVE for Rhino by BuroHappold. This would allow for further investigation into the use of spaces within designed-as-high-performance housing by integrating the qualitative feedback regarding space use and the patterns associated with a design of this particular form factor.

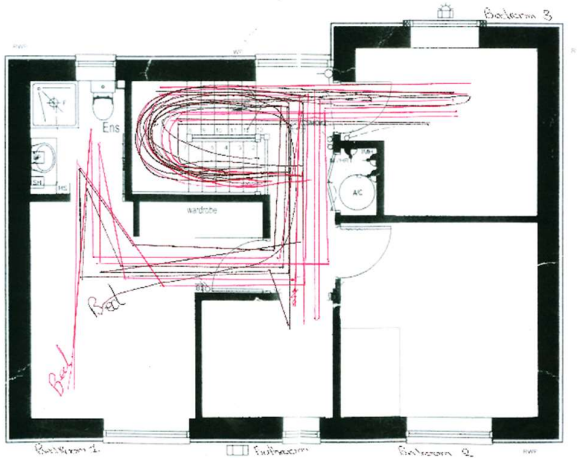


Figure 6 Footfall maps of House A, showing the patterns across First Floor

Conclusions and Limitations

This paper is a non-exhaustive self-review of the methods used to perform a Prove into Occupant Behaviour within a low-cost, targeted Building Performance Evaluation. The questionnaire design was thorough and generated valuable conversation and oral feedback with occupants that registered their comfort levels and behavioural tendencies through recollection and discussions. Due to time constraints, the monitoring period was limited to one year, which for the intents of providing reasonable cause for future research, was sufficient. However additional case studies and more observation time would provide a higher resolution and more in-depth understanding of user behaviour within the confinements of demographic variables and household configurations. Each of the methods provides a rich set of data, providing compatibility between qualitative, quantitative Likert responses and the empirical values calculated from the logs, sufficient to analyse them on their own merit and in depth. The researcher has gained sufficient empirical data in the form of logs and consumption patterns to compile profiles for each household based on their aggregate age totals and social-economic categories. The efficiency of the tools was supported by the subjects' willingness and enthusiasm to participate in the study. Overall the houses kept a similar profile to the predicted model except for accounting for the varying employment options. Further analysis into the baseline consumption of the house that is independent from active occupant interference will be conducted.

Further Research:

A larger sample size would provide ample statistical support increasing the validity of this study/ The study will use additional mini-case studies over a shorter study period as well as using analytical data from building performance databases and questionnaire distribution to measure out the behavioural norms of occupants of high-performance passive built housing. Finally implementing each trend through a detailed IES model to deduce margins compared to design and post-construction data.

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